AUSTRALIAN AQUATIC HABITATS AND BIOTA: THEIR SUITABILITY FOR PALAEOLIMNOLOGICAL INVESTIGATIONS

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Summary

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Australian aquatic habitats are classified briefly. The most suitable sites for palaeolimnological work are crater lakes, which usually provide sequences covering short periods (<<100 000 years), playas in large endorheic basins, and some mound springs with sequences covering long periods (>100 000 years). Deep crater lakes, in which water remains even during the driest periods, should provide the best palaeolimnological records and be the most favourable sites for palaeoclimatological reconstructions since they have well defined enclosed drainage areas, and appropriate hydrological budgets can be calculated. The playa lakes provide information only for major climatic and hydrological changes.

Elements of the aquatic biota which can be fossilised are reviewed. Ostracods and pollen, fruits and spores of aquatic plants currently are the most suitable 'tools' for palaeolimnological studies in Australia. Increased value of insect remains and molluscs (mainly gastropods) requires improved documentation of their ecology. The unsuitability of cladoceran remains and diatoms is discussed briefly.

Key Words: Palaeolimnology, Australia, aquatic biota, lake typology.

Introduction

A classification of Australian aquatic habitats is attempted in order to seek features which characterize such habitats which favour the formation of a waterbody or leave it unchanged, and which alter its condition. The classification facilitates the location of sites best suited to palaeolimnological investigation. Emphasis will be placed on waterbodies unaffected by flowing waters since interest centres on deposits formed under lacustrine aqueous conditions, which suffer little erosion compared to fluviatile deposits. The latter are not ignored, because there are circumstances which permit the preservation of fluviatile sediments.

The aquatic biota and their fossils which can provide information on palaeoenvironments are assessed for their utility in palaeolimnological work in Australia.

Aquatic habitats

All waterbodies examined are athalassic *sensu* Bayly (1967). Saline water referred to here has a salinity above 3‰ following Williams (1964) so contrasting with fresh water (<3‰). Permanent water is the term used to define a waterbody which has not dried in human memory.

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Hutchinson (1957) classified all major types of waterbodies on the basis of their origin. The information given on water chemistry and quality, and the fauna of the various waterbodies, is too diffuse to assist the present study. Bayly & Williams (1973) summarized Hutchinson's (1957) classification and discussed the various processes causing the formation of lakes. Hardie *et al.* (1978) discussed the sediments of saline lakes and distinguished ten major subenvironments. Their classification is broadened here to include fresh waters and to discuss non-lacustrine waterbodies, giving whenever possible additional information on hydrological, chemical and biological data.

The following classification relies on several features of aquatic habitats (e.g. size, mode of origin, location, stability). It is arbitrary and designed for palaeolimnological studies.

Lentic environments

Large closed basins often with extensive internal drainage area

There are many large endorheic basins in Australia, some extending to several hundred km^2. The deepest part of the basin is often referred to as a playa (Reeves 1968, and papers assembled in Neal 1975). Lake Eyre is the best local example. Such playas occur in tectonically controlled basins, whereas others often lie in ancient drainage systems as do many elongated lakes in Western Australia (e.g. Lake Moore—for further details see van de Graaf *et al.* 1978).

Under the present climatic conditions, such basins do not retain permanent water although there is evidence that permanent water occurred in Lakes Eyre and Frome[1]. Either the rate of precipitation and/or evaporation have to be modified, or the supply of water from rivers flowing into the basin has to be modified, or the groundwater table has to rise substantially above the lake floor to allow retention of water for a long period.

During early stages of lake filling, processes of fluvial sedimentation and partial erosion operate. These are superseded by a lacustrine phase. Finally, during an arid phase, formation of a salt crust, followed by efflorescence of salts occasionally rising to the surface, and deflation processes can occur. Pedogenesis and penetration of sediments by roots of phreatophytes can also occur. All these phenomena, associated with an arid phase, can destroy the sedimentological and fossil records (e.g. by erosion, dissolution, diagenesis). The palaeolimnological record of such basins is therefore likely to be incomplete. Only major lacustrine phases with permanent water conditions, resulting from major climatic events and which extend over a long period of time, are likely to be preserved. Ephemeral phases could also be preserved if rapidly superseded by formation of a salt crust, but then many fossils are likely to suffer dissolution or diagenesis. Pollen studies can be useful, as Singh (1981) has shown for a Holocene sequence obtained below a salt crust at Lake Frome. Note that pollen studies are rarely informative on the history of a lake unless pollen of aquatic plants are examined.

The greatest advantage of sequences from large enclosed basins is that they cover long time spans since some basins are very old (e.g. Lake George with a continuous record extending to the Miocene (Singh *et al.* 1981) and Lake Eyre yielding lacustrine sediments at least as old as Lower Miocene (Johns & Ludbrook 1963)).

Sediments will reflect the climatic-hydrological conditions affecting such lakes as illustrated by Hardie & Eugster (1970), Hardie *et al.* (1978), Eugster & Hardie (1978) and Eugster (1980). Similarly, since the water chemistry controls the presence of aquatic organisms there, the fossils will be informative on past hydrological regimes. This is further discussed at the end of this paper.

Small closed basins with minor internal drainage area

These small basins can be formed under a variety of circumstances. Some are defined as interdune corridors, or sabkhas. Others are evaporation-deflation pans, some occurring in ancient drainage systems. Finally, some result from deflation from older lake floors, and there are associated lunettes whose sediment composition is directly controlled by hydrological and climatic regimes: well sorted quartz sand is found in high rainfall areas and a progression occurs from clay to gypsum as aridity increases (Bowler 1976).

Sedimentological and palaeontological records for environments such as lunette lakes do not commonly extend over long periods because they are affected by phases of erosion during parts of a glacial-interglacial cycle. During the same cycle records of sabkhas are usually destroyed when dunes migrate.

The small enclosed basins are likely to fill up with water more frequently than the large ones as their catchment areas are smaller. For both types of lakes, geographical location is important: under today's climate, only the lakes close to the coast are likely to fill up every year, at least for a short period of time, as the periodicity of rainfall is fairly constant there (Gaffney[2]). These lakes yield a particular fauna and flora which either require permanent water (e.g. some ostracods with marine ancestry, fish, bivalve molluscs) or which cannot withstand long periods of desiccation (e.g. amphipods, isopods, cyclopoids which seek refuge during drought). The lakes further inland will yield a less diverse fauna and flora, and erosion of the fossil and sedimentological records caused mainly by deflation processes and efflorescence of salts and clays, will be extensive.

Geomorphological features associated with these small lakes, such as lunettes, and their

[1] Deduced by the presence of the fossil foraminifer *Ammonia beccarii* (indicative of permanent water) in sediment of both lakes: L. Eyre (see Cann & De Deckker 1981) and L. Frome from material received from A. R. Jensen (see Draper & Jensen 1976).

[2] Gaffney, D. O. (1975) Rainfall deficiency and evaporation in relation to drought in Australia. Paper prepared for 46th Anzaas Congress, Canberra, 1975 [available on request from Bureau of Meteorology, Melbourne].

geographical position and sediment composition, will be of palaeoclimatological and hydrological significance (e.g. for lunettes see Bowler 1976). Fossils, however, will only be useful to recognize permanent (often fresh) water phases, as for other phases they are likely to be destroyed or reworked at some stage.

Minor local climatic and hydrological changes should be recorded in the small closed basins in addition to the regional changes.

Coastal lakes

This type of waterbody is most often formed by a barrier dune during changes of sea levels, either by closing an embayment (e.g. Sleaford Mere on the Eyre Peninsula) or by forming a barrier parallel to the coast (e.g. Newland Lake on the Eyre Peninsula). These lakes are associated with features such as barrier dunes which are important markers of past sea level changes. In addition, changes in sediment composition and water chemistry (deduced from the fossil biota) can provide information on sea level fluctuation, since water chemistry is affected by the marine-freshwater groundwater interface, which in turn is influenced by the position of sea level in relation to the lake (see De Deckker *et al.* 1982 for more detail).

Sedimentation in the enclosed bays is unlikely to cover long time spans as barrier dunes can be destroyed easily during subsequent sea level changes. However, barrier dunes which record sea level changes by accreting to one another parallel to the coast will help preserve a mixture of marine and lacustrine sediments covering long periods (e.g. the upper Cainozoic sequence near Robe in southeast South Australia (Cook *et al.* 1977) with some part of it now submerged (Sprigg 1979)).

In both types of coastal lakes the fossil biota should be diverse (since water should always be present) and will contain some marine species which are either reworked, or which survived after their introduction by birds or other processes.

Solution lakes

Such waterbodies, whether small or large are found most commonly in calcareous terrains. If they are deep, valuable palaeolimnological information may be recorded at such sites, but unfortunately this is not the case in Australia. The disadvantage with solution lakes is that as dissolution of the local terrain usually occurs, disturbance of sediments by syndepositional folding and/or faulting is common. On the other hand, as the extent of lacustrine deposition and local terrain dissolution in such environments is climatically controlled, the sediments and fossils are informative on palaeoclimates.

Springs

Of interest are the springs which are associated with mounds. The best known examples in Australia are the mound springs along the margin of the Great Artesian Basin. The springs there are related to structural features and are fed by artesian water (for more detail see Habermehl 1980).

A number of springs are sites of travertine deposition, hence the formation of mounds (for description see Cobb 1975). In other instances, water flow from the springs will be sufficient, at times, to inundate adjacent areas and a swamp or shallow lake will form around them (e.g. Pulbeena and Mowbray Swamps in Tasmania discussed in De Deckker (1982a)). Both types of springs can be successfully used to reconstruct past hydrological regimes (seen by changes of water flows and chemistries).

As the mounds are often indurated, extraction of most fossils (except pollen) will be a difficult task. On the other hand, if water flow remained continuous through time, mound springs should be ideal sites for palaeomagnetic and isotope studies.

Crater lakes

Lakes occupying the inside of volcanic craters, or craters formed by impact of extraterrestrial objects, are occasionally very deep in comparison with other lakes in Australia. These basins, which are rarely more than a few kilometres in diameter, have a well defined and small internal drainage. The most favourable lakes for palaeolimnological work are those in which the water retained has resulted from the combination of precipitation and evaporation over the crater. The deepest lakes often have steep flanks and should retain water throughout most climatic periods, since the lake surface subject to evaporation is greatly reduced compared to other lakes. This remark applies to deep solution lakes as well.

Among crater lakes, the most promising location in Australia to carry out palaeolimnological work is Darwin Crater in W. Tasmania formed by an impact of extraterrestrial material approximately 730,000 years ago (for more detail see Fudali & Ford 1979). Since its formation, it appears to have been the site of a continuous sedimentation (Colhoun & van de Geer, pers. comm.).

Glacial lakes

A variety of waterbodies is formed by glacial action: lakes in large glacial valleys, proglacial lakes, inter-moraine lakes, cirque lakes and those formed by the melting of ice trapped in sediment such as kettle lakes. These features are rare on the Australian mainland except for small inter-moraine and cirque lakes in restricted areas of the Great Dividing Range. The other types of lakes are found in Tasmania. The palaeolimnological record of most of these lakes will only cover short, interglacial periods (except for the proglacial lake) and it is most likely that the lacustrine deposits will have been eroded away by ice scouring the landscape during the following period of glaciation. Additionally, if preserved, the stratigraphical record in these lakes is likely to be incomplete and difficult to correlate.

Large lakes formed in glacial valleys should be most favourable sites for palaeolimnological studies, since they are not always affected by ice during subsequent glaciations. Additionally, work carried out on crustacean remains in alpine lakes outside Australia (Löffler 1975) has already demonstrated the possibility of detecting broad changes in lake stratification caused by either climatological or anthropogenic effects. Elsewhere, Löffler (1978) demonstrated the potential palaeolimnological use of studying crustacean chitinous remains collected in an inter-maraine lake in Ethiopia.

Pools

Since pools are small and ephemeral, and can be destroyed easily, they are of little direct palaeolimnological use. Water chemistry of such pools will be controlled by rain, local soils composition and local geology. It is important, however, to identify floristic and faunistic elements characteristic of such environments in order to detect whether temporary pools were present in larger basins during fairly dry periods. For example in the Pulbeena and Mowbray Swamp deposits in Tasmania, no ostracods typical of temporary pools, such as *Bennelongia australis*, have been recovered which further confirms the concept that water was nearly always permanent at both sites (De Deckker 1982a).

Lotic environments

A number of waterbodies associated with lotic environments can be of some use in palaeolimnological studies; these occur in alluvial fans, stream flood plains, dry river beds and billabongs.

In general, lotic environments are less informative than lentic ones to the palaeolimnologist since the sedimentary sequences in which fossils could be preserved are few: drastic changes of sedimentation often cause extensive erosion. Gauthier (1928, 1951) pointed out that the crustacean fauna, for example, is usually less diverse in pools associated with lotic environments because the occasional waters filling them are sediment-rich which rapidly bury crustaceans and their eggs. The palaeontological record is therefore usually poor. Sedimentological and geomorphological investigations for these environments, rather than palaeontological ones, will be more valuable to the palaeoclimatologist.

Habitats in alluvial fans and stream floodplains

In alluvial fans and stream floodplains, sedimentary deposits can be extensive. Such environments cover very large parts of Australia (e.g. the river channel country in Queensland and a number of alluvial fans in the Flinders Ranges), and their past 'active' phases are significant in detecting past climatic history. Unfortunately, there is little fossil material in these deposits for palaeolimnological work.

Billabongs

Billabongs, or ox-bow lakes, can yield some valuable sedimentological and biological information of relevance to past hydrological phases of large rivers, but usually they do not cover extended periods of time since they are transitory due to the river's continuous meandering. In addition, the sedimentological and biological records can be eroded away or reworked.

Biota

It is pertinent to determine which are the fossils likely to occur in deposits and those which provide best information on water types and water regimes. A detailed assessment of the use of remains of animals found in Quaternary lake and bog sediments was carried out by Frey (1964) and this was summarized and updated by Crisman (1978) who emphasized the information obtainable from cladoceran and dipteran larval remains. This information is briefly re-examined here in the Australian context because there are many halobiont aquatic organisms in Australia of value to palaeolimnological work, but not dealt with by either Frey (1964) or Crisman (1978).

Rhizopoda

Tests of rhizopods can be recovered from sediments. Apart from the study of Cann & De Deckker (1981) which relates to the use of non-marine Foraminifera for determining whether water in saline lakes was either permanent or ephemeral, there is no information available on the ecological requirements of freshwater rhizopods. Their use in palaeolimnological studies in Australia is therefore unknown.

Rotifera

Information on the ecology and distribution of rotifers in Australian lentic waters is still required before a study of egg cases which can fossilize can be undertaken. It also remains to be demonstrated that rotifer eggs can fossilize adequately in all types of environments in Australia and elsewhere.

Porifera

Remains of sponges can easily be recovered from sediments and it is likely that these will be of palaeoecological significance for fresh waters. Although the taxonomy of sponges is well known (Racek 1969), ecological studies are still required before carrying out palaeolimnological studies.

Crustacea

There are many studies on cladoceran remains from many parts of the world but none deal with Australian deposits. It is certain that similar studies will prove to be of palaeolimnological use in Australia for freshwater deposits but ecological work is still lacking. Additionally, as there are only two cladoceran species *Daphniopsis pusilla* and *Moina mongolica* which inhabit saline waters in Australia, remains will not be very informative in studies of saline water deposits. Instead, other groups of organisms which are more diversified in saline waters have to be considered since many waterbodies in Australia are, or were, saline at some stage during their history. Ostracods, for example, are represented by a large number of species in saline and fresh waters in Australia (De Deckker 1981). Some species have restricted ranges of salinity tolerance and therefore are valuable in palaeosalinity reconstructions. Since ostracods have a calcite shell they readily preserve as fossil. They occur in most types of waters except in lotic habitats where they are usually rare and their fauna is much less diverse (except billabongs—see Shiel 1976). Palaeoenvironmental reconstructions using ostracods have already been carried out for a number of waterbodies, e.g. for a large enclosed basin (De Deckker 1982b), mound springs (De Deckker 1982a), maar lakes (De Deckker[3], in prep.) and dissolution lakes (De Deckker *et al.* 1982).

More details on the use of ostracods in reconstructing past environments are provided in De Deckker[3] and De Deckker (in prep.).

Remains of conchostracans should be indicative of temporary pool conditions as they are typical inhabitants of such environments. Only in one case have they been found in a permanent lake (Lake Barrine, Queensland: Timms 1979). However, as explained, temporary pools and their sedimentary records are likely to be destroyed and therefore little emphasis ought to be placed on them.

Fossils remains of aquatic decapods and isopods have rarely been recovered from lacustrine deposits. This could result from the lack of systematic search for them, as remains of the halobiont isopod *Haloniscus searlei* have been found on a number of occasions (De Deckker[3], De Deckker *et al.* 1982). Since the ecology of many species of these large crustaceans is adequately known, their remains, if able to be fossilized, could be valuable to the palaeolimnologist especially for the study of lotic habitats.

Mollusca

Gastropods can fossilize and should be useful in palaeolimnological studies, but in Australia the ecology of this group is poorly known. As gastropods are common inhabitants of a great

[3] De Deckker, P. (1981) Taxonomy, ecology and palaeoecology of ostracods from Australian inland waters. Ph.D. Thesis, University of Adelaide (unpublished).

variety of lotic environments and, as their shells can often withstand the mechanical abrasion so typical of lotic habitats, they should be one of the most suitable fossil groups for examining and interpreting the past history of such environments. Also, extensive taxonomic and ecological work on the halobiont gastropods (e.g. *Coxiella*) is necessary before fossils from saline environments can be examined.

The bivalve molluscs, and their glochidia, preserve under most conditions and should be of use but, once again, ecological data are lacking. As for the gastropods, bivalves would be useful in studies of lotic environments because of their strong and solid shells. Glochidia, however, are fragile and likely to be easily damaged.

Insecta

Remains of many aquatic insects can be found in a variety of fossil deposits but more data on taxonomy and ecology for many groups are required to suit the palaeolimnologist. Outside Australia, studies of the remains of dipteran larvae (e.g. chironomids) are common and have proved to be significant in interpreting past lake histories. In Australia, only the work of Paterson & Walker (1974) on the distribution of two chironomid species from a short core is available. This sort of investigation should prove to be rewarding since there are a number of aquatic insects which also inhabit saline waters (see Williams 1978, Table 3).

Vertebrata

As fishes are present in most permanent aquatic habitats, their bones, if identified at the specific level, could be of palaeoecological significance since fishes are one of the best studied organisms in Australian waters. It is not yet possible to determine species from fossil jaws and otoliths alone. A number of fishes are also known to occur in saline waters and their range of salinity tolerance is well known (Chessman & Williams 1974), but more anatomical data is necessary before they become a useful "tool" in palaeolimnology.

Others

The study of pollen need not be discussed since its utility is well documented and widely used in palaeoecology. Examination of aquatic pollen and spores has been carried out as part of studies of changes of terrestrial vegetation where samples were taken in lacustrine sediments (e.g. Yezdani 1969[4], Dodson 1974a, 1974b, 1975, review of Kershaw's work in Kershaw 1978, Singh *et al.* 1981 and Colhoun *et al.* in press). Since taxonomic and ecological knowledge of aquatic vegetation is already satisfactory (e.g. Aston (1973) for SE Australia), the examination of pollen and seeds of aquatic plants and spores of aquatic ferns, all being readily recovered from lacustrine sediments, can help in the reconstruction of the history of waterbodies. This application is often ignored by palynologists who concentrate on the history of terrestrial vegetation. The detection of changes occurring in a lake through time would assist the interpretation of the non-aquatic pollen sequence recording changes of vegetation surrounding the lake. Additionally, the palaeoecological interpretation from both aquatic and non-aquatic pollen ought to be complementary in palaeoclimatic/palaeoenvironmental reconstructions. The fluctuation of water level for the last 3 million years at Lake George, illustrated by Singh *et al.* (1981) using aquatic pollen and spores and algal remains, produced valuable data.

Study of the ecology of living charophytes and of the morphology of their calcareous oogonia is required before they can become useful in palaeolimnological studies. One charophyte species, *Lamprothamnium papulosum* is also known to occur in saline waters (Burne *et al.* 1980) and a review of the morphological varieties of the oogonia occurring under differing salinities might prove to be of significance in tracing palaeosalinities.

Diatoms, on the other hand, which have proved to be one of the best "tools" in palaeolimnology elsewhere (e.g. for African lakes see Richardson 1968, Richardson *et al.* 1973, Hecky & Kilham 1973, Gasse 1974a, 1974b) are thought to be less important since it appears that diatom frustules do not preserve well in sediments of a large number of aquatic environments in Australia (J. L. Richardson, pers. comm.). The reason for dissolution of the diatoms is at present being investigated by Richardson. However diatom studies for

[4] Yezdani, G. H. (1969) A study of the Quaternary vegetation of western Victoria. Ph.D. Thesis, Monash University (unpublished).

crater lakes in Victoria[4] and by Tudor[5] have shown that such palaeoenvironmental reconstructions can be carried out successfully.

Discussion

Langbein (1961) formulated a relationship between annual precipitation, mean annual temperature and annual runoff for closed lakes. His work was developed further by a number of authors and is summarized by Reeves (1968) to demonstrate the use of hydro-climatic study necessary to determine palaeoclimates. Recently Bowler (1981) attempted to classify present and past hydrological regimes of major Australian lakes. He showed the importance of the various hydrological factors which control the extension of lakes and the amount of water they yield, and he defined a hydrological balance between catchment and lake area. He also examined climatic parameters such as evaporation and precipitation, and determined a hydrological threshold which separates permanent and ephemeral lakes. Depending on climatic conditions, the hydrological regime of a lake will certainly fluctuate and, in some cases, cross the hydrological threshold. To be able to distinguish changes of the relative position of a lake in relation to the hydrological threshold is of great importance in palaeoclimatological studies; such changes can be identified by the presence of organisms indicative of permanent or ephemeral water conditions. Perhaps Bowler's (1981) model should also recognize the importance of the seasonality of rainfall and, more appropriately, the periodicity of rainfall on a long term basis as these have some additional effects on the water budget of lakes in relation to evaporation. It is necessary to recognize rainfall periodicity as this would also surely have a controlling effect on the retention of water in large basins such as Lake Eyre. This is in direct relation to the position of climatic belts, and these could be plotted for the past if the hydrological history of lakes can be reconstructed.

The most favourable location for trapping sediments and fossils is the crater lake. For the palaeolimnologist, it is an ideal site since its catchment area is well defined and the precipitation-evaporation ratio can be estimated adequately. Also if the lake is deep enough to remain moist even during the driest periods, a long continuous record can be recovered.

Large closed basins which are tectonically controlled, and often old geographical features, generally have a less complete stratigraphic record but can sometimes provide very old sequences. The determination of permanence or ephemerality of the water they yield, and the extent of their margins in relation to the area of catchment, is very significant in palaeoclimatology. The smaller closed basins are usually not long lived compared to a glacial-interglacial phase, but will be indicative of particular climatic events (e.g. an arid climate will cause the formation of gypsum lunettes). Often they undergo erosion and sometimes even are completely destroyed during the following glacial-interglacial cycle.

At present, ostracods are the organisms best suited for palaeolimnological studies in Australia since many other potentially useful groups need to be better documented, especially for their taxonomy and ecology. With considerable information already available on aquatic vegetation, palaeobotanists ought to be able to reconstruct lake histories from remains of aquatic vegetation (viz. pollen, spores and seeds).

Gastropods and insect remains are likely to be very useful environmental recorders as demonstrated in studies outside Australia, but further local taxonomic and ecological work is necessary. The study of cladoceran remains in Australia is not as useful a tool compared to elsewhere since many Australian waterbodies are, or have been, saline and therefore unsuitable for most cladoceran taxa. Diatom studies will not be as rewarding as elsewhere since it appears that diatom frustules do not preserve in most aquatic environments in Australia.

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